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BOND BEHAVIOUR OF THE POST-INSTALLED BUNDLED REBARS ANCHORS WITH CEMENT MORTAR IN HARDENED CONCRETE

BY

BOGDAN ROŞCA[1,*] and ZOLTÁN KISS[2]

[1]Technical University of Iași
Faculty of Civil Engineering and Bulding Services,
[2]Technical University of Cluj-Napoca
Faculty of Civil Engineering

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Abstract. An experimental study on the bond behaviour of the post-installed bundled rebars anchors into hardened concrete is presented. The bonding material is a fly ash Portland cement based mortar which was obtained by previous laborator studies and successfully used at the anchorage of the rebars. The bond behaviour of the bundled anchor is depicted by the bond strength, displacement of the loaded end at the control and failure load and also by the failure modes. A bundled anchor consists in three rebars which are tied by welding straps. The pull-out tests were performed according with the european standards. The results indicate a satisfactory pull-out behaviour somehow superior against an circular rebar anchor of equivalent cross-section area. The bundled anchor can be used for a ratio r between the diameter of the drilled hole and the diameter of the equivalent circular section of the anchor smaller than the ratio which was recommend by author in some previous studies, where rebars anchor of circular section are embedded into hardened concrete with cement mortar.

Key words: bundled anchor; rebars; fly ash; cement; bonding mortar.

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[*]Corresponding author: *e-mail:* roscabogdan@yahoo.com

1. Introduction

In practice more and more connections between reinforced concrete members are carried out by bonding deformed reinforcing bars with an adhesive mortar in holes drilled into existing concrete. Holes are usually drilled in existing concrete with hammer or diamond drilling machines. After cleanning the hole, the adhesive mortar is injected or poured.

In the view of author the installed rebars in hardened concrete with cement mortar with maximum aggregate size between 2 and 4 mm requires a ratio r between diameter of the drilled hole and diameter of the rebar at least 1,8, so as to the failure mode should by pulling out of the embedded rebar from mortar or by breaking of the rebar (Roşca, 2014). For a such ratio *r,* where bar sizes with diameter greater than 18 mm are used, the diameter of the drilled hole results greater than 30 mm. Such situation involves additional costs concerning drilling of the hole because requires changing the clamping system of the drill bit.

2. Objectives

The objective of this study is to assess the pull-out behaviour of the bundled anchors which were embedded into hardened concrete with cement mortar by the assessement of the bond strength, maximum displacement of the loaded end and failure mode. Comparision with the behaviour of a single rebar anchor embedded in the same conditions and some remarks on effectiveness of the gripping system for the end of the anchor is to be made.

3. Bond Behaviour of a Single Post-Installed Rebar Without Connection Reinforcement

The bond behaviour of a single post-installed rebars with adhesive mortar may be significantly influenced by many parameters as the bonding material, geometric characteristic of the anchorage, installation conditions, environmental conditions, hardened concrete characteristics and type of loading. The influence of these parameters is comprehensively discussed in literature (Eligehausen *et al*., 2006.

The Part 6 from SREN 1504 states that to grout reinforcing steel bars in concrete structures, the following products are typically used: synthetic resins, cement based materials or a mixture of these in either fluid or thixotropic consistency. It has been shown by confined pullout test that post-installed rebars can behave as cast-in-place rebars, provided that a suitable product is used and the installation is done propely (Spieth *et al*., 2001). Different behaviour is observed at elevated temperature and in craked concrete.

Even if the installation is done properly and the hole cleaning is done perfectly there are large differences between the bond behaviour of different products (Spieth *et al.*, 2001). Concerning to the bonding product, in Fig. 1 different behaviours of post-installed rebars fixed with different bonding products are shown. All bars were installed with large concrete cover to prevent splitting of concrete. The curves show that rebars embedded with different products have a different behaviour in respect to stiffness and bond strength (Spieth *et al.*, 2001). Comparing the stiffness of the bonding products for post-installed rebars from Fig. 1, it can be noted that the Epoxy System is the greatest while the polyester system is the lowest in value. The Hybrid System (a mixture of Vinylester and cementious compounds) has a behaviour closest to a cast-in-place rebar. Comparing the bond strength of the bonding products for post-installed rebars from the same figure it can be noted that the Epoxy System and Hybrid System are the greatest while the polyester system is the lowest in value.

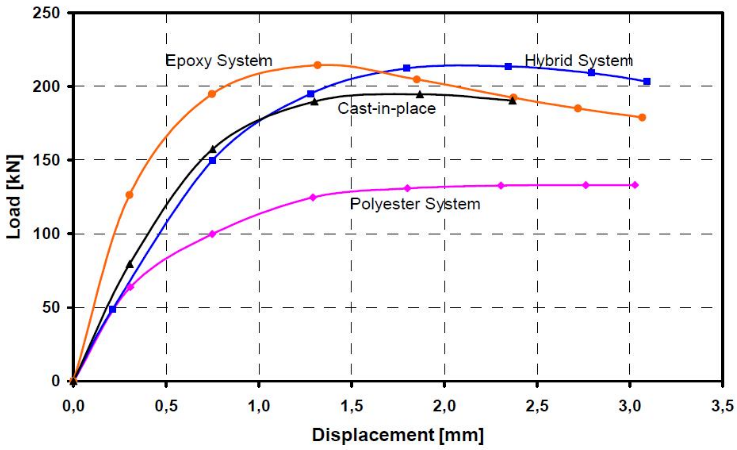
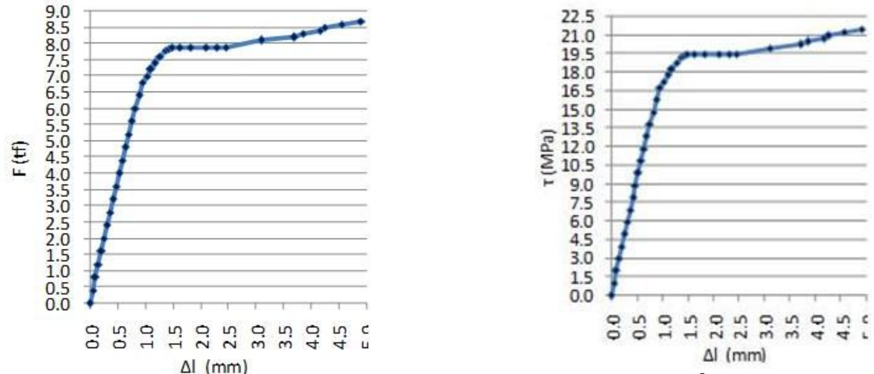


Fig. 1 – Load displacement curves of post-installed and cast-in-place bars measured in a confined pullout test (Spieth *et al*., 2001).

An alternative for the foregoing mentioned bonding products, which is less used and studied, is the cement mortar of high strength. In the last years due to improvements in technology of concrete, new mixture of cement based mortar providing fluidity in the fresh state and high strength in the hardened state can be obtained. For example, in Fig. 2 the load displacement curve in confined pullout test for a single post-installed rebar with cement mortar without polymers in hardened concrete is given (Roşca, 2014). It can be noted that the bond strength, which is calculated at the interface between steel and mortar, is conventionally enough to replace a cast-in-place reinforcing steel bar with a post-installed rebar according to European standards (TR023, 2006).



a *b*

Fig. 2 – Behaviour of a single post-installed rebar in hardened concrete with cement mortar (Roşca, 2014): *a* – load-displacement curve; *b* – bond strength-displacement curve.

4. Materials and Methods

The used anchoring mortar is a mixture of Portland-composite cement, aggregate, water and chemical admixture. The blended cement used in this study was the cement CEM II/A-V 42,5 which includes 6-20% fly ash grounded with Portland clinker at manufacturing.

The aggregate consist of sand, which was divided into two categories as coarse and fine sand. The natural river sand, which is considered round and less rough, was used. The maximum size coarse aggregate (MSA) was 2mm, but some trials with 4mm were performed. The used chemical admixture is the polycarboxylate superplasticizer (PCE).

4.1. Bonding Mortar Properties

In Table 1, 2 the strength properties of the bonding mortar, which was used in this study, are given. Specific gravity is given, too.

Table 1
Compressive Strength; Average Values

Mix	Specific gravity	Compressive strength in MPa		
		24 h	7 days	28 days
1.	2230	28.3	53.50	63.50

Table 2
Tensile Strength; Average Values

Mix	Tensile strength by bending in MPa			Tensile strength by splitting in MPa		
	24 h	7 days	28 days	24 h	7 days	28 days
1.	5.52	8.28	9.18	3.18	4.34	4.72

In Table 3 the elasticity modulus and shrinkage strain for the bonding mortar, which were used in this study, are given. All the characteristics of the bonding mortar in hardened state, which are presented in Tables 1,…,3, were determined in a previous study in accordance with european standards (Roşca *et al.*, 2014).

Table 3
Elasticity Modulus and Dry Shrinkage Strain; Average Values

Mix	Elasticity modulus in MPa		Value of the dry shrinkage after 55days	
	7 day	28 day	mm/m	μm/m
1.	36,000	38,000	0.720	720

4.2. Bundled Anchor

The bundled anchor consists in three reinforcing bars which are tied by equally spanned welding straps, see Fig. 3. The diameter of rebars is equal to 10mm. The area of the three bundled rebars is equivalent with a circular cross-section area with 17.32 mm diameter. The reinforcing steel is PC52 and the chemical and mechanical characteristics are covered by SREN 438-1. Two series of five bundled anchors were involved into tests, the first serie is provided with welding straps over all length of the anchor and later with welding straps over all half length of the anchor.

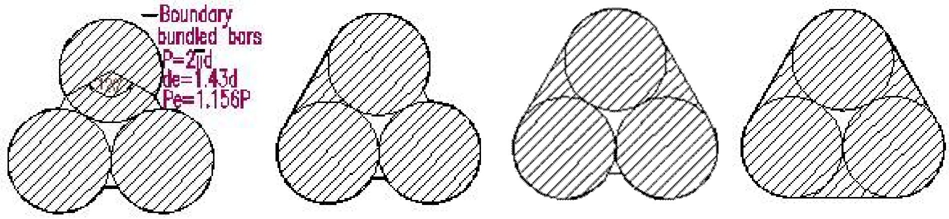

a

B

Fig. 3 – Anchors made of three bundled bars with equally spanned welding straps: *a* – welding straps over all length of the anchor; *b* – welding straps over half length of the anchor

Studing the possibilities of placing of the welding straps onto a bundled anchor, three types of cross-section are possible to create. In Fig. 4 *b*, *c*, *d*, it can be seen that the cross-section of the bundled anchor is able to cut one, two or three welding straps. In Fig. 4 it can be also seen how the contact area of the bundled rebars anchor decreases with the increase of welding straps on the cross section. Nevertheless considering that the boundary of the circular section for one bar with the other two is limited to an arc of 120 degree, then based on a trigonometric calculus the decrease of the contact boundary is quite small.

It is important to mention that the surface of welding which is in contact with the bonding mortar is not rough enough comparing with the ribs of the rebars. However it is presumed that the influence of the welding straps on pull-out behavior consist in a stronger wedging effect of the weldings into mortar.

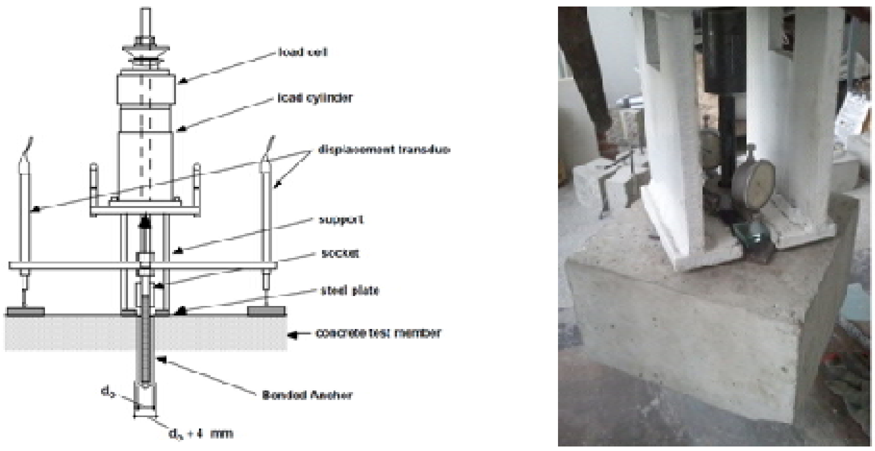


a $P = 2\pi d - 0.05d$ *b* $P = 2\pi d - 0.1d$ *c* $P = 2\pi d - 0.15d$ *d*

Fig. 4 – Decreasing of the contact area of the bundled rebars anchor with the increase of the welding points; cross-section: *a* – without welding points; *b* – with one welding point; *c* – with two welding points; *d* – with three welding points.

4.3. Test Method of the Bond Resistance

The bond strength of the rebars was determined based on the information given in EOTA TR023 and SREN 1881. Both standards are limited to reinforcing steel bars designed in accordance with SREN 1992-1-1. Besides many tests provided by Part5 of ETAG 001, which are required for common bonded anchors, can be omitted because the tests will prove only that the post-installed rebar connection have a comparable behaviour as cast-in-place rebar connection under different influences (EOTA ETAG001, 2002). Therefore, only tension load can be transferred to cast-in-place rebar connections in accordance with EC2, shear on rebars will not be considered (EOTA TR023).



a *b*

Fig. 5 – *a* – Example of pull-out test rig for confined tests in accordance with TR023 (EOTA ETAG001, 2002); *b* – Developed tension test rig for confined tests for this study.

The tests should be performed in non-cracked concrete with deformed rebars that have properties in accordance with Annex C of EC2 with f_{yk} greater or equal than 500 MPa and the relative rib area f_R between 0.05 and 0.10.

The confined pull-out test is recommended by TR023 for rebars, see Fig. 5 *a* (EOTA ETAG001, 2002). In confined test the concrete cone failure is eliminated by transferring the reaction force close to the anchor into concrete.

4.4. Assessment of the Bond Strength

The bond strength f_b is calculated from equilibrium equation between ultimate value of the external force N_{um} and adherence stress developed onto the contact area between anchor and surrounding mortar. The adherence stress distribution onto the embedded end of the anchor is considered constant. For a such stress distribution the equation to calculate the bond strength is

$$f_b = \frac{N_{um}}{\pi d l_v}, \tag{1}$$

The average value of the bond strength f_{bm} for all serie of five anchors is calculated and reported. It can be noted that the bond strength which is calculated with the equation (1) do not take into consideration the influence of ribs of the rebars. Normally such equation is more appropriate for plain bars.

For ribbed bars in accordance with EOTA TR23, the average bond strength is calculated by:

$$f_{bm}^t = \frac{N_{um}}{\pi d l_v}\left(\frac{0.08}{f_R}\right)^{0.4}, \tag{2}$$

with f_{bm}^t is the average bond strength in the test series; N_{um} – average value of the failure $N_{u(fc)}$ loads in the test series; d – rebar diameter; l_v – embedment length of the rebar in concrete; f_R – relative rib area of the rebars; $N_{u(f_c)}$ – failure (peak) load of an individual test converted to concrete class C20/25 or C50/60.

The failure peak load of the test is conventionally set as follows (EOTA ETAG001, 2002):

a) if peak load is reached at a displacement $\delta \le \delta_1$, then use peak load as failure load.

b) if peak load is reached at a displacement load at $\delta \le \delta_1$, then use load at δ_1 as failure load.

The limit δ_1 is called maximum acceptable displacement and in accordance with TR023 depends on the diameter of the rebar. For rebar diameters smaller than 25 mm, the δ_1 is equal to 1.5 mm.

Based on information provided by EOTA TR023, it shall be shown by test that the post-installed rebar system can develop the same design values of the bond resistance with the same safety margin as cast-in-place rebars according to EC2 (EOTA ETAG001, 2002). In the Table 4 in accordance with TR023, the required bond strength for post-installed rebars in hardened concrete are given. In Table 4 it can be seen that the required bond strength for post-installed rebars is at least four times greater than the design values provided by EC2 for pre-installed rebars. This situation occurs because the values of the bond strength which are given in SREN 1992-1-1 (EC2) are set for the worst bond condition, minimum concrete cover and minimum allowance space between bars.

Table 4

Concrete strength	Design values of the ultimate bond strength according to EC2 for good bond in MPa	Required bond strength for post-installed rebars according to TR023
C20/25	2.3	10.0
C25/30	2.7	11.6
C30/37	3.0	13.1
C35/45	3.4	14.5
C40/50	3.7	15.9
C45/55	4.0	17.2
C50/60	4.3	18.4

4.5. Installation and Applied Testing Procedure of the Bundled Rebars Anchor

In Table 5 information about anchoring characteristics and bonding mortar are given. The ratio between the diameter of drilled hole h_o and the diameter of equivalent circular section of the bundled anchor d_{se} is 1.73. The embedment length was 93 mm that means approximately 5.5 times the diameter of equivalent circular section d_{se}.

Table 5

Anchoring characteristics								Bonding mortar	
Bundled anchor				Drilled hole		Concrete block		Compressive strength	
Steel	No. bars	Diam d_s, [mm]	Diam. equiv. d_{se}, [mm]	Depth h_o, [mm]	Diam d_q, [mm]	Size mm	Class	7 days MPa	28 days MPa
PC52	3	10	17.32	93	30	300x300	C35/45	46.5	55.5

The confined pull-out test procedure were performed in accordance with the recommendations given in ETAG001 Part5. The test was performed in load control and the pull-out load was progressively increased in such away that the peak load had occured to 1 to 3 min after the start (SREN 1504-6). In addition to the standard components of the test rig presented in Fig. 5 *a*, to increase the concrete confined effect between the steel test rig and the concrete specimen a steel plate of 8mm thick with a hole of 38mm diameter in the centroid was placed. Two series of five specimens were involved into the tests. Some bundled anchors were provided with threaded end and as gripping system a threaded socket was used, and for all the rest of anchors without threaded end a barrel wedge system was used to pull-out the anchors. All pull-out tests were performed at 7 days after the installation of the bundled anchors.

Testing machine can develop a maximum force 1,000 kN and is provided with 3 force scales. On the lower scale de machine develops a maximum force of 100 kN and the precision is 0.5 kN.

5. Results

The installation of these bundled anchors is extremely facile because the cross-section enables an easy flowing out of the fluid mortar where the anchor is embedded into drilled hole. This observation is valid for the developed bonding mortars with any aggregate size smaller than 4mm.

In Tables 6 and 7 experimental results of the pull-out tests for bundled anchors installed with/without welding straps into the developed bonding mortar are given. The pull-out forces and bond strengths which are included into the tables are average values calculated from a serie of 5 tests.

Table 6

Pull-Out Experimental Results at 7 Days for Bundled Rebars;the Embedded End Contains Welding Straps

Characteristics			Concrete support C35/45	
			Embedment length 93mm (≈5.5d_{se})	
			Bundled	Circular equivalent
			3Φ10mm	1Φ17.32mm
Average value of the failure loads $N_{u(fc)}$	N_{um}		9.08	
Average bond strength in the test series	f_{bm}, [MPa]		15.91	17.93
Average bond strength – according TR023	f'_{bm}, [MPa]		18.34	20.67
Displacement at the control load F	δ_c mm	min.	0.35	
		max	0.39	
Maximum displacement at the failure loads $N_{u(fc)}$	δ_{max} mm	min.	1.5	
		max	1.5	
Average yielding force	F_{ym}, [tf]		–	
Average maximum failure force	$F_{max,failure}$, [tf]		9.70	
Failure mode through:			S-M	

In Fig. 6 pull-out failure modes are shown. For the bundled anchors with threaded end, the failure occurred by breaking of the threaded end, and therefore this gripping system is not suitable to pull out the anchor from concrete block. When the gripping system consisted in a barrel and wedge system was applied, the bond failure occured at the boundary between steel anchor and mortar (S-M), *i.e*. the anchor was pulled-out of the bonding mortar.

Table 7
Pull-Out Experimental Results at 7 Days for Bundled Rebars;the Embedded End is Free of Weldings Straps

Characteristics			Concrete support C35/45	
			Embedment length 93 mm (≈5.5d_{se})	
			Bundled	Circular equivalent
			3Φ10 mm	1Φ17.32 mm
Average value of the failure loads $N_{u(fc)}$	N_{um}		7.13	
Average bond strength in the test series	f_{bm}, [MPa]		12.19	14.08
Average bond strength – according TR023	f'_{bm}, [MPa]		14.06	16.24
Displacement at the control load F	δ_c mm	min.	0.50	
		max	0.55	
Maximum displacement at the failure loads $N_{u(fc)}$	$\delta_{\max}$ mm	min.	1.5	
		max	1.5	
Average yielding force	F_{ym}, [tf]		–	
Average maximum failure force	$F_{\max,\text{failure}}$, [tf]		8.17	
Failure mode through:			S-M	

The results given in the Tables 6 and 7 show that the average bond strength between steel and mortar exhibits comparable values with values which were calculated at pull-out test for circular rebars, see Fig. 2 (Roşca *et al*., 2014).

a *b*

Fig. 6 – Failure modes of some bundled anchors which are embedded 5.5d (93 mm): *a* – early breaking of the anchor through thread where a threaded couple (socket) is used; *b* – pulling-out of the anchor from mortar (S-M steel to mortar failure mode) where barel and wedge gripping system is used; 2 pieces in view.

In Table 6 displacement of the loaded end is quite low against the control displacement (0.6 mm); this is a quite notable experimental result. From Table 7 it can be observed that the displacement of the loaded end for bundled anchor without embedded welding straps is greater than the displacement where there are embedded weldings. A better bond behavior of the end with welding straps could be only explained by a better wedging effect of the straps into surrounding mortar. It must be noted that displacement of the loaded end at the control load for the first group of bundled anchors is even lower than the displacement for a circular rebar anchor of Φ16 mm, which it is supposed that has a greater depth of the ribs.

There are differences in MPa regarding the calculated average bond strength for both the bundled anchor and the equivalent circular cross-section anchor because, for the first the length of contact boundary of the cross-section with the mortar is approximately 16% greater than the perimeter of cross-section for the latest; the calculus equation is the same.

The failure mode for the tested series of bundled anchors, with/without embedded weldings straps, is by pulling-out of the anchor from bonding mortar, see Fig. 6 *b*. This kind of failure can be achieved only if a barrel and wedge gripping system is used.

6. Conclusions

The study deems a single installation configuration of anchors, namely three bundled bars of 10mm diameter each, which are embedded 93mm (approximately $5.5d_{se}$) into drilled holes of 30 mm diameter. Therefore, the ratio *r* beetween the diameter of drilled hole and the diameter of an equivalent circular section for the bundled anchor is equal to 1.73 mm. The bundled bars are made by PC52 reinforcing steel. The bundled anchors were splitted into two groups, with/without welding straps embedded into the bonding mortar.

Bonding mortar is a fly ash cement based mortar with maximum aggregate size equal to 2 mm. Some trials were made with mortar with maximum aggregate size equal to 4 mm. The embedment length was calculated in order to avoid yielding stage into the steel anchor during the pull-out test.

Hardened bonding mortar exhibits high compression strength and satisfactory elasticity modulus. The axial tensile strength is comparable with C50/60 concrete strength class. Characteristics of the bonding mortar were the subject of some previous studies.

The performed pull-out tests show that average bond strength values which are calculated at the interface between steel and mortar are high, and considering information provided by Table 4, it can be assert that bonding mortar provides a good anchoring of the steel rebars into hardened concrete of any class between C12/15 up to C50/60.

The displacement of the loaded end to a level a force equal to control load is quite low especialy for the group of anchors with welding straps embedded into bonding mortar. This is a quite unexpected result, considering that the ribs for the Φ16 mm rebar are much higher than for the Φ10 mm rebar.

The failure mode on the confined pull-out test is that expected, namely at the interface between steel and mortar.

The wedge and barrel gripping system is more effective in pulling out the anchor than the threded socket.

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COMPORTAREA LA SMULGERE A CONECTORILOR DIN PACHETE DE BARE DE OȚEL BETON POSTINSTALAȚI CU MORTAR DE CIMENT IN BETON INTARIT

(Rezumat)

Se prezintă un studiu cu privire la comportarea la smulgere a conectorilor alcătuiți din pachete de bare de oțel beton postinstalați în blocuri de beton simplu.

Materialul de legătură este un mortar special pe bază de ciment Portland cu adaos de cenuşă de termocentrală la fabricare, care a fost elaborat prin studii specifice de laborator şi utilizat cu succes la ancorarea de bare de armătură. Comportarea la smulgere a conectorilor din pachete de bare de oțel beton este descrisă prin efortul unitar de aderență ultim, valoarea deplasării capătului conectorului la încărcarea de control, încărcarea de cedare maximă convențională, precum şi prin modul de cedare. Pachetele de bare sunt formate din 3 bare solidarizate cu cordoane de sudură. Încercările la smulgere au fost efectuate conform standardelor europene. Rezultatele studiului arată o comportare bună la tracțiune a conectorului în pachet de bare oarecum superioară unui conector de oțel beton de secțiune circulară echivalentă. Se poate afirma că acest tip de conector din 3 bare de otel beton în pachet se poate utiliza în condiții de siguranță în cazul unui raport *r* între diametrul găurii forate şi diametrul secțiunii circulare echivalente pentru cele 3 bare în pachet mai mic decât raportul minim recomandat de autor în studii anterioare atunci când conectori de oțel beton cu secțiune circulară sunt instalați cu mortar de ciment în elemente de beton.